The Status of Urban Stream Restoration in the United States

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Introduction

The modernization of society and the growth of population centers have led to a subsequent decline in the quality of numerous watersheds and associated riverine ecosystems. In recent years there have been significant efforts to “restore” river systems to a more natural state thereby reversing the effectives of development. Examples of typical urban stream restoration projects include bank stabilization, de-channelization of artificially straightened and hardened reaches, channel daylighting of closed conduit streams, dam and culvert removal, creation of stream access points, and aquatic and terrestrial habitat improvement. To promote and further river restoration efforts, the River Restoration Committee was formed in 1996 inside the Environmental and Water Resources Institute’s Hydraulics and Waterways Council. As knowledge in the restoration field increased, it became apparent that there are distinct differences between urban and rural restoration projects and that urban stream restoration needed to be one of the core focuses of the committee. Restoration of urban streams requires unique approaches because human activities associated with urban development permanently alter a stream’s hydrology, geomorphology, water quality, and ecology from its original “natural” state. This recognized need led the parent River Restoration Committee to form an Urban Stream Restoration Task Committee in the summer of 2001. The task committee functions with three primary goals:

1. To encourage and facilitate discussion on urban stream restoration through conference activities, workshops, publications, and public outreach. Sharing of information among a wide audience is crucial to the future of restoration activities and projects.
2. Advance the knowledge of fundamental physical, chemical, and ecological properties of urban streams by promoting collaboration and communication between researchers and practitioners. Increasing the technical knowledge of urban streams and watersheds will lead to the development of best management practices and sustainable designs to improve the water quality and ecological health of urban streams.
3. Promote identified best management practices and sustainable designs while addressing infrastructure objectives and constraints found in urban areas.

In support of these goals, the committee recently completed a review of regional urban stream restoration practices as well as an assessment of restoration research activities being conducted on urban streams. The preliminary results of these two activities were presented at the 2003 World Water and Environmental Resources Congress in Philadelphia (Carpenter et al 2003; Schwartz et al 2003). The purpose of this paper and presentation is to update the community on the state of urban stream restoration in the United States by providing an update on these two endeavors. Ultimately, the authors hope it facilitates an active exchange of ideas among colleagues involved in improving restoration principles and practices in urban streams.

Urban Stream Restoration

The Urban Environment

When describing restoration projects, frequently the terminology is urban *stream* restoration for urban projects and river restoration for rural projects. This is because a majority of urban restoration projects occur on smaller tributaries within urban environments while "larger" *river* restoration projects are undertaken in rural areas where the physical and political boundaries are less restrictive.

The need to distinguish urban stream restoration from general restoration approaches is evident by how dramatic human activities permanently change the fluvial system within an urban watershed. In fact, stream restoration as defined by the National Research Council (1992), as "a return of an ecosystem to a close approximation of its condition prior to disturbance", is simply not possible in urban watersheds. Other restoration definitions have been more appropriately developed, such as rehabilitation (Booth et al. 2001), and naturalization (Rhoads and Herricks 1996). Because of the common use of the term "restoration" in the engineering practice, we use it here understanding that the urban condition limits what can be achieved.

Urban streams differ from rural streams in many ways. For example, urban watersheds, with varying degrees of imperviousness, tend to have a wide variety of flow regimes ranging from high peaks with short duration to low (or even no) base flows. As the amount of impervious increases, the frequency of bankfull events increases while access to undeveloped floodplains decreases. Furthermore, bankfull indicators are more difficult to find in urban streams due to changing hydrologic conditions, degraded stream banks, physical changes to the streams (relocated sections), placement of man-made structures, and loss of riparian vegetation. In addition to hydrologic changes, urban streams tend to be more confined due to infrastructure. Frequent transportation crossings and utilities, particularly gravity sewer lines, are located in or across historic floodplains. Urban streams tend to have more structures such as culverts and bridges, and in some cases dams. These structures alter flow hydraulics and may further limit access to floodplains.

Changing sediment regimes in urban streams can also have dramatic effects on the form of a stream. Typically high sediment loads with finer particle sizes are produced in developing areas and enter the stream environment during storm events. The hydrologic changes caused by development can also destabilize an urban stream, which increases local bank erosion beyond its natural rate. Urban streams can also suffer from the other extreme when they are starved for sediment and thus erode the bed resulting in an incised channel. Impervious areas limit areas that can erode and stormwater detention ponds or reservoirs capture sediment-laden flows. An unbalanced sediment regime is caused from these changes in sediment transport rates and sediment properties. It is not unusual to find areas of extreme scour and other areas of rapid aggradation in the same urban river system, such that the stream morphology appears much different from a pre-disturbed condition.

Problems relating to water quality are also different in urban streams. Non-point source pollutants enter the receiving waters during storm events. In addition to increased sediment loads, storm flows flush nutrients, oils, and metals out of the atmosphere and off the pavement. Fecal coliform contamination is common in urban areas, especially if the wastewater treatment facilities cannot keep pace with community growth or many old septic systems are failing. In addition to chemical pollution, thermal pollution can cause habitat degradation. Heat from rooftops and blacktop pavements is absorbed by the rainfall and runoff and these heated waters enter channel systems. These problems can then be further acerbated by thermal pollution from the loss of riparian vegetation and high width/depth ratios (low base flows cover a wider area at a shallower depth).

Finally, urban communities have different concerns relating to streams than their rural counterparts. Public access, public safety, habitat, and aesthetics all enter the debate on what a “restored” stream should look like. Woody vegetation serves an important role in bank stability and in-stream and riparian habitat, however, some people prefer the aesthetics and perceived safety of an open, more park like view.

Established Urban Stream Restoration Techniques

Stream restoration projects include reintroducing meanders to straightened reaches using a “natural” channel design approach, channel daylighting of closed conduit streams, bed and bank stabilization, dam and culvert removal, and habitat improvement. The “natural” channel design approach analyzes existing channel form, and prescribes a planform alignment consisting of meander wavelength and radius of curvature, a cross-sectional area from hydraulic geometry relationships, and riffle spacing for bed structure (Rosgen 1996). If land space near stream is available, reconnection of the floodplain occurs as part the overall project. Daylighting of a channel that has been forced into a closed conduit is more problematic, because restoring the channel to “natural” condition typically cannot be achieved within the existing constraints imposed by urban development. However, daylighting projects are a popular form of urban stream restoration and projects have been completed from coast to coast (Pinkham, 2000).

Stabilization of the streambed through hydraulic grade control measures is major focus of stream restoration work because hydrological changes often lead to stream degradation. In channel (or in-stream) structures that have typically been used to stabilize the bed include Newbury weirs or riffles (Newbury and Gaboury 1993), step-pool structures, gabions, and weir structures constructed of wood or rock.

Bank stabilization is a key component of almost all urban stream restoration practices because of increased lateral erosion. Bank stabilization includes structures to either armor against or divert high-velocity flows away from banks, particularly at bends were the bank toe is especially vulnerable to erosion. In-channel structures that are typically used to stabilize the bank include boulder placements at the bank toe, vortex rock weirs, log vanes, woody debris and root wads. Bioengineering approaches on the channel side slopes include planting trees and grass, live staking (live branch layering) and tree revetments. Other bioengineering practices include terracing, the use of biodegradable erosion control blankets and non-degradable geotextile (filter fabric) before vegetation gets established, brush bundles and coconut fiber bio-logs at the toe of the channel bank, bank riprap covered with topsoil and mulch, and organic soil amendments. These approaches are more aesthetically pleasing than “hard” engineered approaches such as concrete retaining walls and gabions.

Reconnecting a channel to its floodplain is typically accomplished by modifying the channel cross-sectional shape coupled with raising the bed invert as part of the “natural” channel design protocols. This approach often requires excavation in the floodplain to achieve a more natural hydraulic geometry. This cross-sectional modification is always coupled with raising the streambed invert by using hydraulic grade controls, such as riffle weirs. Another approach is creating an intermediate floodplain bench within an incised channel. In urban environments raising the channel bed is not always acceptable from a flood control perspective. Therefore a way to meet flood and erosion control goals an multi-objective approach would be to stabilize the incised channel with grade control and to develop an intermediate floodplain bench within the incised floodway.

In some cases, in-stream habitat enhancement is a goal of the restoration project and in other cases it is a by-product of channel stabilization approaches. Habitat enhancement structures include pool-riffle structures, step-pool structures, boulder placements, large woody debris, root wads, bottomless arch culverts for safer fish passage and lunker boxes. These features provide diversity in the streambed and improve habitat for various species.

For more information on stream restoration techniques, the Stream Corridor Restoration Manual by the Federal Interagency Stream Restoration Working Group provides an excellent overview of the subject (FISRWG, 1998). However, it should be noted this manual was not written for the urban environment and lacks detailed design standards. The U.S. Army Corps of Engineers has produced an engineering manual on the subject - Hydraulic Design of Stream Restoration Projects (Copeland, 2001). However, designers should use caution when determining restoration technique viability since many accepted stream restoration practices for rural environments are not applicable to urban settings (Fischenich, 2001). A review of urban stream restoration techniques can be found in Urban Stream Assessment by Brown (2000). The techniques covered by Brown are common across a majority of the United States.

Research in Urban Stream Restoration

Classification and Assessment of Urban Watersheds and Streams

In general, the classification and assessment of watersheds and streams is based on geology and soils, stream geomorphological characteristics, physical habitat structure (Montgomery and Buffington 1993; Rosgen 1996; Raven 1998; Frothingham et al. 2002), and current and future land use. Such classifications are usually hierarchical and organized into different scales, for example, valley types, channel reaches, pool-riffle bedforms, and bed material. Classification and assessment procedures provide the basic interpretative data to make judgment of corrective measures. The geomorphic classification of rural streams developed by Rosgen (1996) is widely used to characterize streams, and is the initial step in stream restoration design in many states. However, proper use of this technique in the urban environment has been a debated issue (Miller and Skidmore 2001; Callahan 2001). Thorne (1998) has also developed a stream assessment protocol, which many designers use as an alternative procedure to Rosgen's methodology.

Classification and assessment of geomorphic characteristics is essential, but more information is needed to assess the urban stream condition so that water quality and ecological information is included. One example is the Rapid Stream Assessment Technique (RSAT) developed by the Center of Watershed Protection (1999). It uses a qualitative procedure to assess stream condition that includes the following categories: 1) channel stability, 2) channel scouring and sediment deposition, 3) physical instream habitat, 4) water quality, and 5) riparian habitat, and 6) biological indicators.

More research is needed to improve the classification and assessment of urban watersheds and streams that better link physical and water quality metrics with ecological degradation (Kondolf 1995; Booth et al. 2001). Concepts of habitat classification, for use in urban stream restoration, need to be orientated towards the physical and ecological conditions of an urban system. Improved protocols for classification and assessment of urban watersheds and streams will contribute to more effective management and planning.

Urban Watershed Management and Planning

Watershed management and planning efforts in urban environments commonly are implemented at three scales related to restoration techniques (USEPA 1995). They are: 1) *upland and watershed techniques*: related to the control of non-point source inputs from best management practices (BMPs), including hydrological runoff characteristics from increased impervious surfaces; 2) *riparian techniques*: re-establishment of vegetative canopy in the riparian corridor; and 3) *instream techniques*: applied directly to the active channel including natural channel design approaches restoring planform and hydraulic geometry, morphological complexity and streambed and bank stability.

Implementation of these techniques is greatly influenced by the need to mitigate hydrologic modifications and water quality problems, development pressures on the floodplain and in riparian zones, and socioeconomic and political integration for restoration projects. Stormwater management programs must be integrated with overall watershed management strategies to address the mitigation of hydrologic modifications and the increase in runoff pollutants. Research on the effectiveness of stormwater BMP design and performance on the impact mitigation to urban streams is on-going (Urbonas 2001). A major issue is that even after BMP implementation in many cases urban streams remain degraded. This finding illustrates the complexity of the urban problem where chemical and physical factors both contribute to degradation and the associated impacts the biological community.

Instream techniques for restoration of the channel are used for a variety of reasons, though most urban projects implement them for flood and erosion control and aquatic habitat enhancement. Project planning for instream techniques must be integrated with watershed and riparian techniques through socioeconomic considerations that include land values, urban renewal, riverfront access, recreation, linear greenways, and aesthetic enhancements. A new attitude emerging among some urban water managers is that a marriage between technical solutions and public input is a key factor in success of such programs (Brooks and Palmer 1999; Rhoads et al. 1999; Wade et al. 2002). Stream naturalization as a restoration framework recognizes that planning and design is achievable through community-based decision-making (Rhoads and Herricks 1996). Accommodating the wide range of interests among stakeholders may be one of the biggest challenges in implementing watershed restoration/protection efforts (Eden et al. 2000). Being able to integrate complex technical, legal, and economic issues is imperative, particularly when engineering design criteria is needed to reduce a level of uncertainty because project failure from property damage is very costly. More research is needed to improve methods of technical transfer to the stakeholder from scientists and engineers, particularly with the exchange of complex assessment and planning strategies.

Natural Channel Design Approaches in Urban Streams

Traditional design of open channels in urban areas has emphasized prismatic trapezoidal or rectangular sections with rigid armored boundaries. Their impacts on aesthetics, recreation opportunities, property value, and ecological health have been well documented, and such designs are seldom acceptable today. Consequently, there has been a movement towards designs that simulate "natural " conditions. In general, principles and practices in stream restoration utilize one or more of the following techniques: 1) empirical relationships related to channel pattern, regional hydraulic geometry curves for channel dimensions, and applied regime theory for erodible channels, 2) reference site conditions, and 3) deterministic models from hydraulic and sediment transport engineering (Hey 2002).

Current practice for natural channel design approach combines the use of empirical relationships from geomorphic principles and reference site conditions to support designs aimed at restoring channel stability (Brooks and Sear 1996; Rosgen 1996; FISRWG

1998; Heaton et al. 2002). The basic philosophy underpinning the natural channel design approach are based on two main assumptions 1) creation of channel and banks within the applied concepts of a dynamic equilibrium are stable, and 2) channel stability supports higher quality habitat providing for a healthy ecosystem (Brown et al. 2002).

The natural design approach is difficult to apply to, and often inappropriate for, watersheds that are facing increasing runoff rates due to urban land use changes. In these situations, the channel forming or dominant discharge, and corresponding bankfull dimensions are in flux. Detailed hydrologic studies are necessary to forecast future flow characteristics rather than relying on past flow data or bankfull indicators. Unlike rural areas, urban channel design should include flood flow hydraulic analysis of water profiles and stability to help insure public safety. Channels with mobile boundaries are not always desirable where bridges, buildings, utilities, or water quality issues exist. Restoration design priorities in urban streams must be modified considering these limitations (Rosgen 1997; Doll et al. 2002); and have been organized as follows: 1) re-establish the channel on its previous floodplain, 2) re-establish the channel and floodplain at the stream's existing elevation, 3) covert stream types without creating an active floodplain, and 4) stabilize the channel in place. A design that stabilizes a channel in place could hardly be consistent with the basic philosophy of the natural channel design approach. Further research is needed to clarify the limitations of this restoration approach for channel design in urban streams.

A key issue with the natural channel design approach in urban streams is that a reference condition is of limited use for steam reaches with dynamic hydrologic and sediment regimes, and morphologies controlled by local infrastructure. In addition, application of regional hydraulic geometry curves that they are based on reference data from rural streams is not an acceptable practice. To correct this deficiency, regional curves developed specifically for urban streams are just emerging in restoration practice (Doll et al. 2002). Johnson and Heil (1996) recognize the importance of developing more specific regional curves, but also indicate a confidence interval or some measure of uncertainty with use is needed to facilitate improved design efforts. In general, more research is needed to explore the use regional curves for urban streams (Wilkerson 1998; Brunner 1999), however the inherent instability and previous disturbance of urban streams will be a challenge.

One criticism of the natural channel design approach is that once the basic channel dimensions are determined, minimal engineering criteria exist to aid practitioners in the selection and design of instream structures. Many types of instream structural practices are used in urban streams (Brown 2000; Carpenter et al. 2003); however, the choice of instream structural practices for a restoration project is commonly based on popularity and familiarity (Walsh 2002). Research is needed to evaluate the performance of these structural practices for use in urban streams since they were originally intended for rural restoration projects. Improved design criteria of these structures based on hydraulic research must include variables related to dominant and/or peak discharges, sediment transport capacity and rates, bed sediment and bank soil properties, and complexity of morphological settings. Recent progress through research has been made in developing better design criteria for instream structural practices, for example Johnson et al. (2002a) examined design of hydraulic control structures near bridges. Their research evaluated the effectiveness of vanes, cross-vanes, and w-weirs for preventing scour at bridge abutments and suggested optimum design parameters based on laboratory experiments that could also be used in restoration projects. A design procedure was developed for sizing step-pool structures in higher gradient streams (Thomas et al. 2000). Use of large woody debris (LWD) in urban streams was evaluated for morphological and ecological benefits with a review of LWD stable orientation (Larson et al. 2001). Johnson et al. (2002b) recommend that an adaptive management strategy be applied to improve these design guidelines through more effective post-construction monitoring and greater sharing of data among the professional community.

In order to improve upon the natural channel design approach in urban streams, the basic guiding principle of channel stability is sound, but further technological advancements to the approach are needed (Fischenich 2002). Advancements include 1) the use of deterministic modeling tools in engineering hydrodynamics and sediment transport, and 2) the use of ecological criteria based on pre-construction bioassessment so that proper design of habitat enhancement structures can be achieved. Overall, the greatest research need is the development of design protocols that integrates ecological criteria operationally with the use of deterministic modeling tools in engineering (Booker and Dunbar 2004; Pasternack et al. 2004). With the apparent need for advanced approaches and the limited utility of reference condition data, a design framework for urban stream restoration should be process-orientated and habitat-based (Booth et al. 2001; Schwartz et al. 2001).

Ecological Health in Urban Streams

Improvement of ecological health of an urban stream cannot always be assumed through the implementation of a natural channel design approach. Recent results evaluating the ecological success of restoration practices have been mixed, ranging from increased fish and macroinvertebrate densities (Moerke and Lamberti 1999) to reduced biodiversity in restored areas (Jack et al. 2002; Pike et al. 2002). A broad, watershed view is needed in urban stream restoration to address potential impacts related to water quality, physical habitat, or both. Ultimately the true measure of success in stream restoration is how the aquatic community responds to the applied treatments.

Complex relationships between physical habitat structure and ecological integrity are not well understood in urban streams. A few studies have been conducted in this area. Booth and others (2001) documents consequences of urban development on stream morphology, habitat, and biotic community in urban streams in the Pacific Northwest, and begins to address issues related to the fundamental geomorphic, hydraulic and ecological processes that influence physical and biological degradation. Hession (2001) investigated the role of riparian forest corridors in maintaining ecological health of urban streams. Other research has included “developing an improved method for designing and optimizing environmental flow” by identifying hydraulic flow events that trigger key ecological processes and link them to specific biological processes or the life-cycles of organisms;

examples of such events include periods when: 1) bed sediments are mobilized, 2) large woody debris and backwaters are inundated, 3) the stream bed is exposed, and 4) benches and the floodplain are inundated (Walsh 2002). Overall, a wide range of research is needed in this area, including the development of habitat-based design criteria through the integration of geomorphic, hydraulic, and ecological principles; and standardization of pre-construction biomonitoring protocols relevant to the urban stream.

Summary Points: Critical Research Needs

This review of current principles and practices for urban stream restoration, and associated research underscores several critical research needs:

1) Improved understanding of fundamental geomorphic, hydraulic and ecological processes that influence physical and biological degradation in urbanizing streams;
2) Improved classification and assessment protocols of watershed and streams that account for the urban condition recognizing the influence of water quality, physical habitat degradation, and a stressed ecosystem;
3) Improved watershed management and planning methods that assesses vulnerability from urbanization through process-orientated “threshold” metrics that better predict impacts to hydrology, morphology and physical habitat, water quality, and ecology;
4) Development of regional hydraulic geometry equations specifically for urban streams;
5) Improved engineering design criteria for use of instream structures based on a relevant characterization of channel stability for the urban condition;
6) Advancement of the restoration design methods through use of multidimensional hydrodynamic models, dynamic sediment transport models, and aquatic habitat models;
7) Development of a restoration design framework for instream structural practices that integrates geomorphic, hydraulic, and ecological processes; and
8) Improved pre- and post-construction monitoring protocols of the stream condition, including measures of channel stability, physical habitat, and biological integrity, in order to compare with traditional restoration practices, and verify their long-term performance.

Regional Preferences and Accepted Practices

Implementation of stream restoration activities in urban watersheds are motivated by agencies, individuals, and groups wanting to alleviate the problems and issues listed above. The planning and design of these projects tends to be local in nature so there exists potential for regional preferences and accepted practices. To illuminate regional differences, an investigative study was conducted to define regional practices. It was and is envisioned that much can be gained from sharing information between and within regions, however, the social, economic, political, physical, and climatic differences must be considered in the planning and design of urban stream restoration projects.

For this project, the continental United States was divided into eight regions based primarily on geography (Pacific Northwest, California, Southwest, Midwest, Great

Lakes, Southeast, Mid-Atlantic, and Northeast). For each region, a literature search and Internet search were performed to determine the state of practice of urban stream restoration for that region. In many cases, personal communication with regional authorities and design experts was also part of the process. Each regional section represents a sample of urban stream restoration activities in that region and should not be viewed as a comprehensive picture, but rather as a starting point for increased dialog within and between regions. The details of this review can by found in Carpenter et al (2003), but Table 1 provides a summary of the findings. Again, it's important to recognize this is an overview of activity within the urban environments of each region. It is not all-inclusive and is not meant to represent a review of all restoration projects.

Table 1: Urban Stream Restoration Activity Review

Region	**Level of Activity**	**Typical Concerns**	**Typical Treatments**
Pacific Northwest	High	Salmonid Migration, Water Quality, Temperature, Aesthetics, Habitat, Endangered Species, Sediment Loads	Bed and Bank Stabilization, Culvert Removal, Natural Channel Design, Sediment Controls, Spawning Gravel Maintenance, Instream Habitat Enhancement, Watershed and Stormwater Master Plans
California	High	Flooding, Water Quality, Aesthetics, and Habitat	Bed and Bank Stabilization, Channel Daylighting, Sediment Controls, Natural Channel Design
Southwest	Low	Habitat, Aesthetics, Wetland Creation	Bed and Bank Stabilization, Sediment Controls
Midwest	Medium	Watershed Restoration, Flooding, Habitat	Bed and Bank Stabilization, Natural Channel Design, Habitat Enhancement, Watershed and Stormwater Master Plans
Great Lakes	Medium	Watershed Restoration, Habitat, Recreation, Sediment Loads, Aesthetics, Water Quality	Bed and Bank Stabilization, Natural Channel Design, Instream Habitat Enhancement, Dam Removal, Channel Daylighting, Watershed and Stormwater Master Plans
Southeast	Low	Water Quality, Sediment Control, Aesthetics, Habitat	Bed and Bank Stabilization, Natural Channel Design, Habitat Enhancement, Channel Daylighting
Mid-Atlantic	High	Water Quality, Sediment Control, Flooding, Infrastructure Protection, Stormwater Control	Bed and Bank Stabilization, Natural Channel Design, Habitat Enhancement, Sediment Controls, Watershed and Stormwater Master Plans
Northeast	High	Water Quality, Aesthetics, Recreation, Habitat, Infrastructure Protection	Bed and Bank Stabilization, Natural Channel Design, Dam Removal, Habitat Enhancement

Overall, it was determined that the level of activity varied significantly between and within regions. For example, in the Southeast there are relatively few documented urban stream restoration projects, but North Carolina is a leader in urban stream restoration practices. A similar situation existed in the Southwest where Central Texas (Austin and San Antonio) had higher levels of activity than the rest of the region. In addition, it was determined the driving force behind the projects varied significantly between regions. For example, Salmonid Migration is the main driver behind urban projects in the Pacific Northwest (primarily Portland and Seattle), whereas water recreation and aesthetics are commonly identified as project goals in the Northeast. Finally, it was determined that many of the techniques utilized were relatively consistent with each region employing similar methods for bed and bank stabilization and versions of natural channel design. However, the acceptance of bioengineering techniques varied between regions, as did the types of habitat enhancement. The variability in habitat enhancement is an important finding since local fish populations should determine the suitability of habitat (for example rootwads versus lunker boxes). In conclusion, there is still much to be learned about restoration for the urban environment.

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